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SPATIAL AND TEMPORAL VARIABILITY OF SWIR AIR GLOW MEASUREMENTS:POSTPRINT

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Technical Report

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Spatial and Temporal Variability of SWIR Air Glow Measurements

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Abstract

It is well known that luminance from photo-chemical reactions of hydroxyl ions in the upper atmosphere (~85 km altitude) produces a significant amount of night time radiation in the short wave infra-red (SWIR) band between 0.9 and 1.7 μm wave length. This has been demonstrated as an effective illumination source for night time imaging applications. It addition it has been shown that observation of the spatial and temporal variations of the illumination can be used to characterize atmospheric tidal wave actions in the sky glow region. These spatio-temporal variations manifest themselves as traveling wave patterns whose period and velocity are related to the wind velocity at 85 km as well as the turbulence induced by atmospheric vertical instabilities. Ground to space observation systems especially those employing adaptive optics are adversely affected by high altitude turbulence and winds. In this paper we propose the use of sky glow observations to predict and characterize image system degradation due to upper atmosphere turbulence.

1.0 INTRODUCTION

Sky glow from chemical luminescence in the upper atmosphere has been observed at a number of different wavelengths [1-3]. In the short wave infra-red (SWIR) between 1.0 μm and 1.7 μm, it is due to emissions from hydroxyl radicals transitioning from excited rotational and translational states to lower energy states and emitting a SWIR photon in the process.

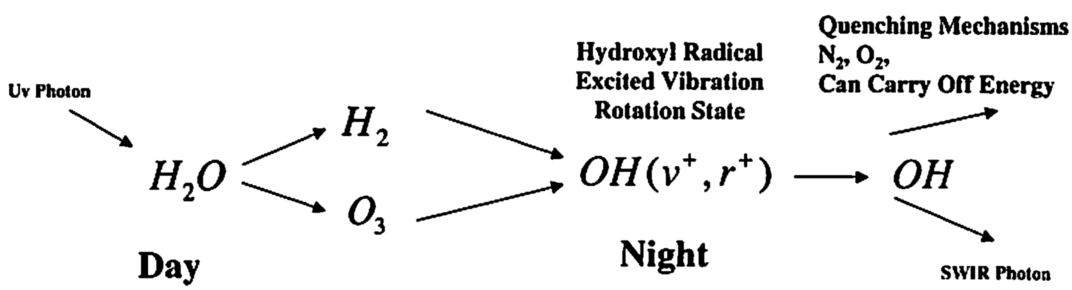


Figure 1.1 Synoptic Sketch of the Air Glow Process in the Infra-Red.

Figure 1.1 is a synoptic sketch of the air glow process for production of illumination in the SWIR band. Although the chemical reactions are very complicated, the overall effects can be summarized as follows. During the day, UV photons strike water molecules and initiate the production of hydrogen and ozone. At night, the hydrogen and ozone recombine and form the excited hydroxyl radicals with elevated vibration and rotational energy states. The molecules then transition to a lower energy state emitting a SWIR photon. The process can be quenched by other molecules, among them O_2 and N_2, which carry off the energy.

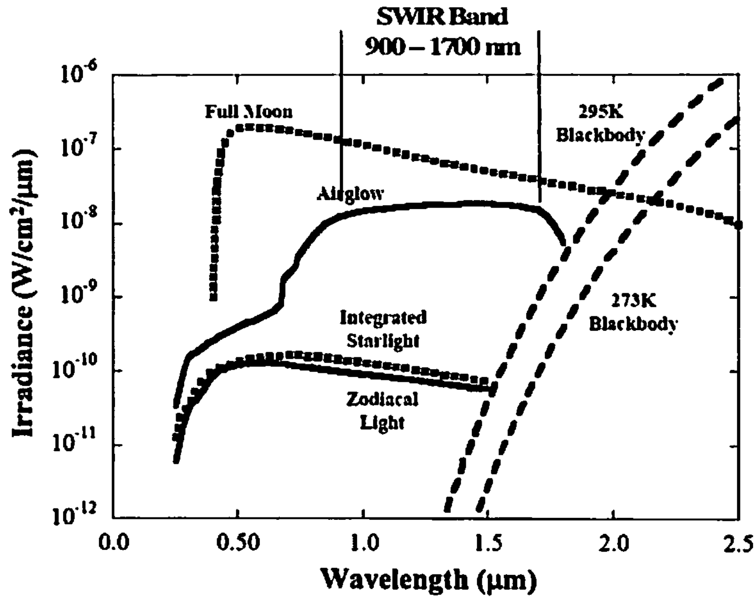


Figure 1.2 Night Time Illumination Sources

Figure 1.2 shows sources of night time illumination that can be used for imaging [1]. Of course the brightest source is the moon. When the moon is not out, or is obscured by clouds, figure 1.2 shows that sky glow provides a significant source much greater than thermal radiation in the SWIR band.

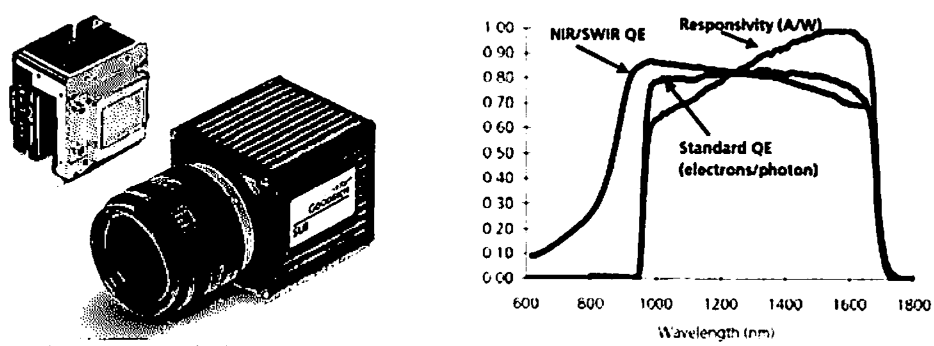


Figure 1.3 Sensors Unlimited SWIR Camera Used to Make SWIR Measurements of Sky Glow.

The SWIR camera used for the measurements was a Sensors Unlimited model 320KTX with 320x240x40 μm pixels. The camera has quantum efficiency above 60 % from 900 nm to 1700 nm as shown in the curve in figure 1.3. The effective read noise of the camera was about 50 equivalent detected photons per pixel.

SWIR image measurements shown in the subsequent sections were made using an F/1.4 50 mm focal length camera lens. With SWIR air glow irradiance levels, optics faster than F/2.5 are typically required for passive night glow imaging in order to concentrate enough light onto the detector array.

In order to make comparisons, two visible cameras were used in conjunction with the SWIR, an intensified CCD camera operated at 30 Hz, and a low noise CCD camera with 1 second exposures.

2.0 Gravity Wave Formation

Gravity wave formation is a function of the wind shear and the atmospheric vertical thermal stability. We want to consider the formation of gravity waves in the upper atmosphere in the region of the sky glow. Note that atmospheric gravity waves as described here should not be confused with relativistic gravity waves, which are a much different phenomena.

Several relevant equations follow.

Vertical Shear of Horizontal Wind

$$S = \left[\left(\frac{du}{dz}\right)^2 + \left(\frac{dv}{dz}\right)^2\right]^{0.5} \tag{2.1}$$

were u and v are the two orthogonal components of the horizontal wind velocity.

Bunt-Vaisala Frequency Squared

$$N^2 = \frac{g}{T}\left[\left(\frac{dT}{dz}\right) - \left(\frac{dT_{ADA}}{dz}\right)\right] \tag{2.2}$$

$$Ri = \frac{N^2}{S^2} \tag{2.3}$$

A large Richardson number implies atmospheric stratification, while a small number implies turbulent wave formation.

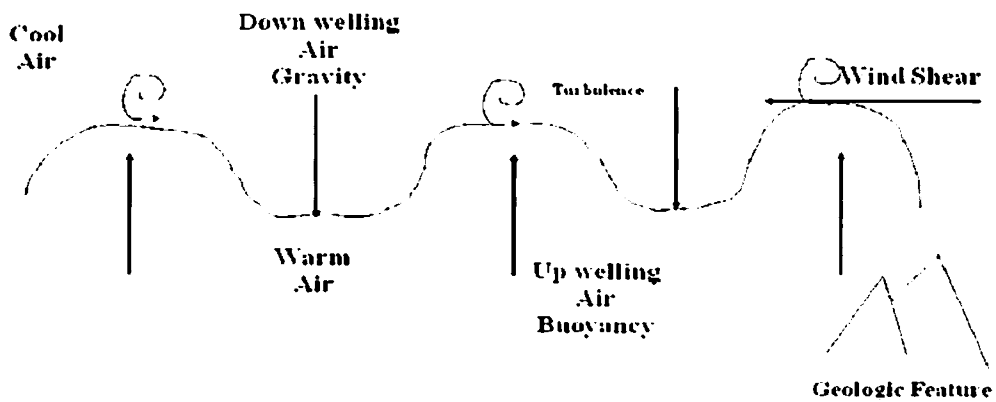


Figure 2.1 Wind Shear Initiates Gravity Waves.

Observed gravity waves can be related back to the velocity, direction, and shear of upper atmospheric winds at approximately 80 Km.

3.0 MEASUREMENTS

Image measurements of sky glow wave patterns were primarily carried out at a rural site on the west coast of the Hawaiian island of Kauai. The Kauai site has very little ambient illumination other than direct and scattered moonlight.

3.1 KAUAI SITE

The Kauai measurement site is located on the west coast of the island with very little in the way of ambient street or housing light pollution. When the moon is not out, the only source of illumination is from the sky glow.

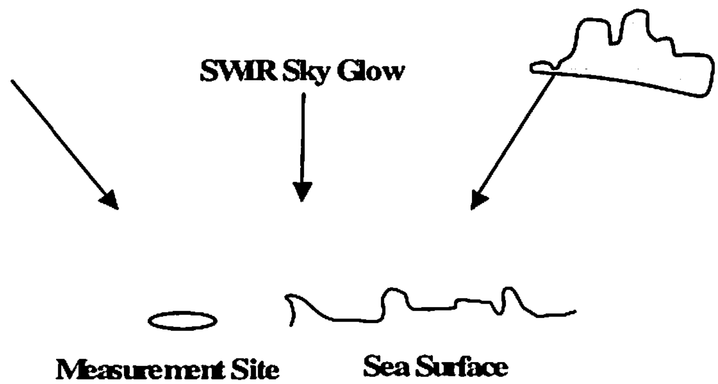
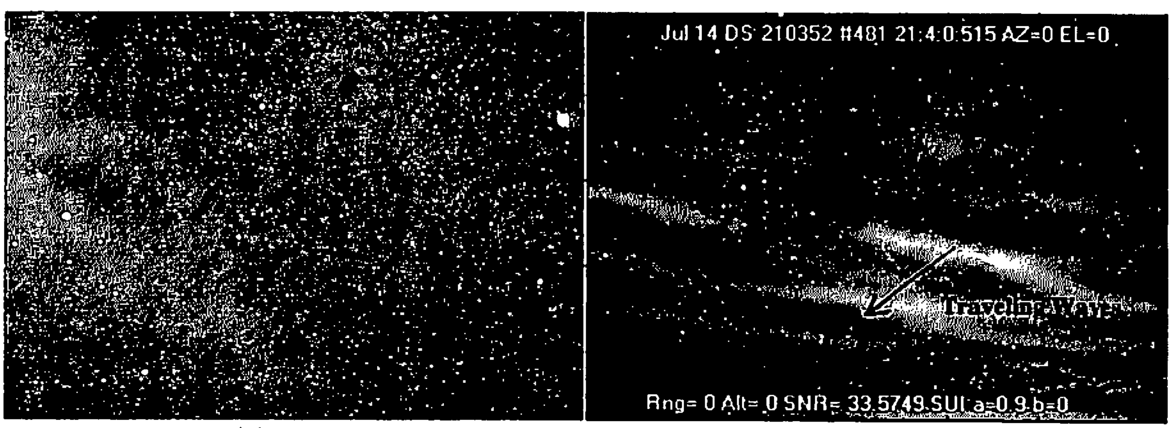


Figure 3.1 Kauai Rural Measurement Site



Visible Camera SWIR Camera

Figure 3.2 Visible and SWIR images from Kauai Site Showing Sky Glow Traveling Wave Patterns.

Figure 3.2 shows some intense striations in the sky glow radiance from the Kauai site. The irradiance from these striations was about 4.1×10^{-8} Watts per cm^2.

If we consider the direction and speed of the traveling waves we can estimate the speed and direction of the winds aloft. In addition if we consider the peak to valley modulation of the waves we can estimate the wind shear at altitude. Using this information in conjunction with the equations in section 2 we can ascertain information abouth the upper atmosphere wind speed and turbulence.

Visible Camera SWIR Camera

Figure 3.3 Sky Glow Measurements showing low Contrast Wave Pattern.

Figure 3.3 shows sky glow wave pattern with a lower contrast than that shown in figure 3.2. This indicates that the vertical instability described in section 2 is not as intense as during the time period shown in figure 3.2.

The sky glow camera has been mounted to an AZ,EL gimbal in order to obtain scans of the full sky hemi-sphere in an automated fashion. The gimbal moves to a series of positions arranged in an annular pattern. At each position 30 seconds of image data are collected. The scan pattern is illustrated in figure 2.6.

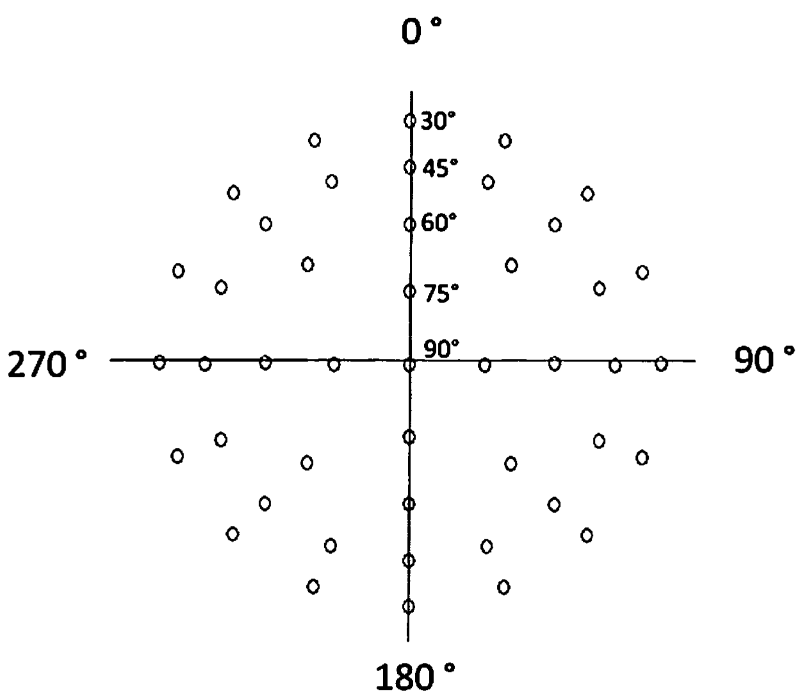


Figure 3.4 Annular Scan Pattern for Recording Sky Glow from the Full Sky

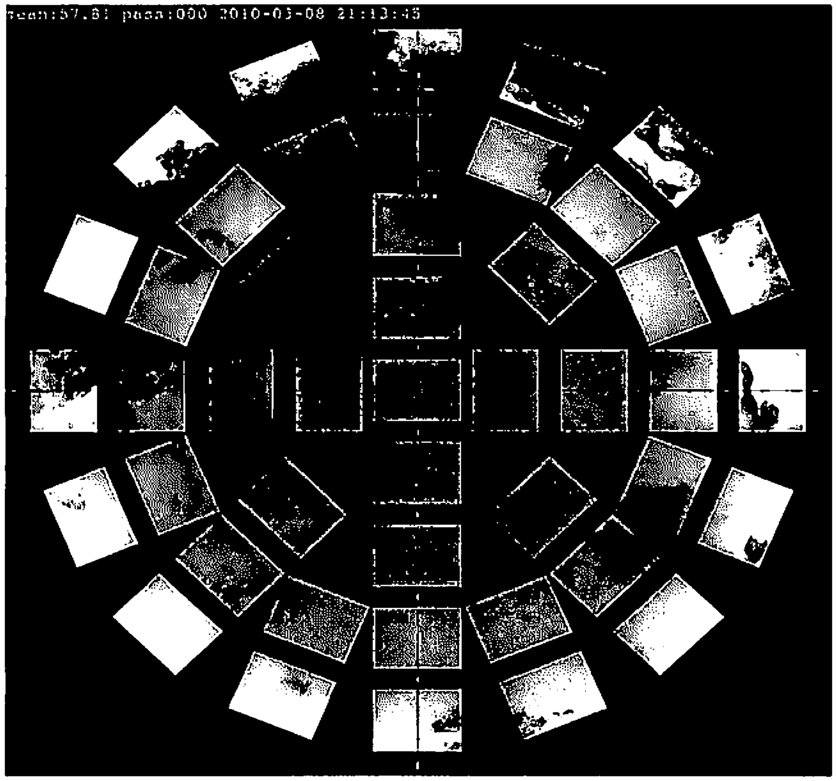
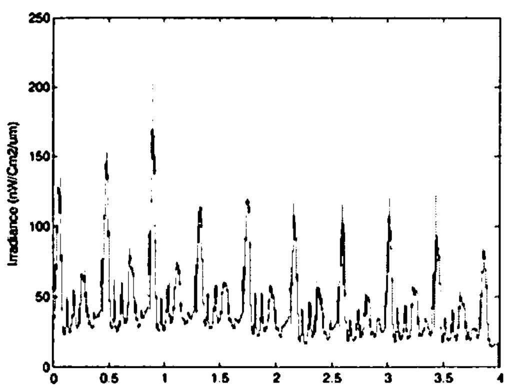
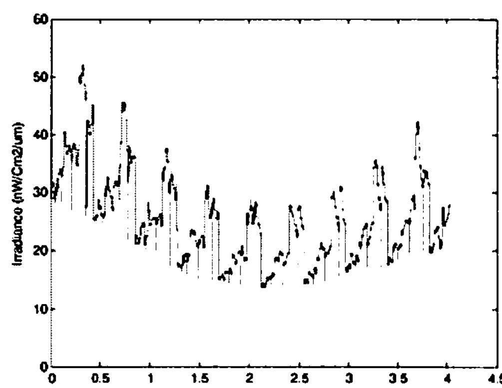


Figure 3.5 Annular Scan Pattern for Recording Sky Glow from the Full Sky

Figure 3.5 shows image frames that were collected at each of the scan positions shown in figure 2.6. The dark regions in the images are water clouds. The image frames are arranged in the same annular pattern as the scan pattern. Although all the image frames are not collected at exactly the same time, this collage presents a look at the sky glow hemisphere. It can be seen from the collage that the images taken near the horizon, on the outer ring, are brighter than those in the center. This is due to the fact that the sky glow intensity varies approximately as the cosine of the elevation angel from the horizon.



a) Intensity Pattern Showing Little Long Term Variation



b) Intensity Pattern Showing Large Long Term Variation

Figure 3.6 Annular Scan Pattern for Recording Sky Glow from the Full Sky

Next figure 3.6 shows time series plots for sky glow data taken on two different nights in Kauai. Each point on the plot represents an average of the sky glow intensity over an image frame. As the gimbal moves through its annular scan pattern, we can see periodic fluctuations in the plots. This is due to variations of the intensity with elevation angle. The peaks in the time series occur when the gimbal is pointed near the horizon, and the minima when the gimbal is pointed near zenith. Comparing figures 2.8 a) and 2.8 b) we can see long term fluctuations in the mean intensity as well. This is particularly noticeable in figure b) where we see dip in the long term intensity at about the 2 hour point.

Intuition would indicate that the sky glow should diminish as the night progresses due to depletion of the chemical constituents. However we have found no indication of this in the data. We often see fluctuation in the mean sky glow over the night, however there appears to be no clear trend.

Zenith Angle	SWIR SKY Glow Irradiance Kauai
-85	3.9×10^{-8} W/cm^2
-80	2.3×10^{-8} W/cm^2
-75	2.5×10^{-8} W/cm^2
-65	1.3×10^{-8} W/cm^2
-35	4.6×10^{-9} W/cm^2
-20	4.5×10^{-9} W/cm^2
0	8.0×10^{-9} W/cm^2

Table 2 Sky Glow Radiance Measurements as a Function of Zenith Angle Kauai Site.

4.0 CONCLUSIONS

Chemical luminescence from excited hydroxyl radicals in the upper atmosphere at about 80 km provides a natural illumination source for night time imaging in the SWIR band between 1.0 and 1.7 μm. A series of image measurements have been made of sky glow radiation on the west coast of Kauai, Hawaii. The irradiance levels measured were consistent with published levels as shown in figure 3.1

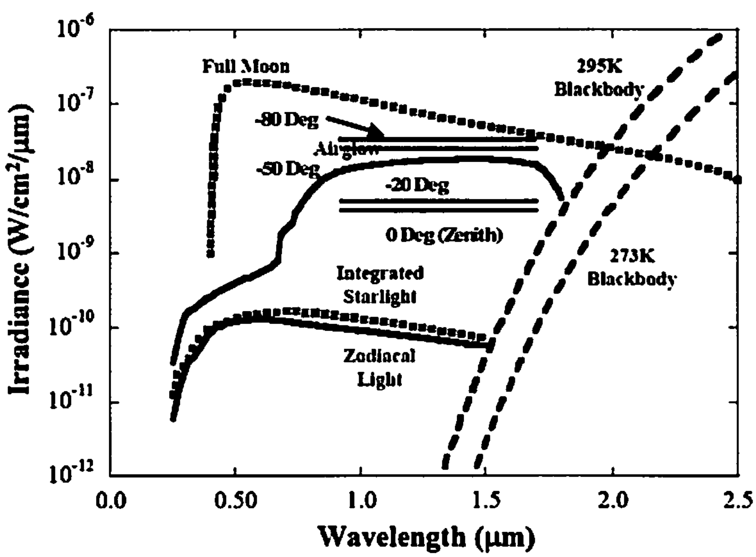


Figure 4.1 Night Time Illumination Sources With Sky Glow Measurements Superposed.

Section 2 described the formation of gravity waves in the upper atmosphere caused be vertical instabilities and wind shear. In this paper we propose the use of visual measurements of sky glow wave formations, induced by the gravity waves, to estimate the turbulence in the upper atmosphere. This may be significant for predicting the performance of adaptive optics systems.

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